# An Efficient Power-Saving Mechanism for Integration of WLAN and Cellular Networks

SuKyoung Lee, *Member, IEEE*, SungHoon Seo, *Member, IEEE*, and Nada Golmie *Member, IEEE*

***Abstract*— In this letter, we propose an efficient power-saving mechanism using paging of cellular networks for WLAN in heterogeneous wireless networks, where WLAN interface is turned off during idle state without any periodic wake-up in order to save power consumption while at the same time, the existing paging of cellular network is utilized in place of beacons in WLAN. For the proposed mechanism, the mean power consumption is investigated via analytical and simulation results.**

***Index Terms*— WLAN, cellular networks, power-saving, vertical handoff.**

## I. INTRODUCTION

ONE OF THE most impending requirements to support seamless communication environment in heterogeneous wireless networks comes from the limited power supply of small-size mobile terminals as in standalone Wireless Local Area Networks (WLANs) or cellular networks. As a result, it is a challenge to maintain mobile users' active connections as they move across different types of networks, that is known as "vertical handoff", optimizing the overall system performance such as power consumption [1].

Here, it is worthy of notice that when connected to the WLAN, a WLAN interface card is usually in idle mode for around 70% of the overall time. In most of the existing vertical handoff management schemes [1], [2], a Mobile Node (MN) must turn on its WLAN interface even in the idle state with power-save mode to receive periodic beacon signals from Access Points (APs) and periodic page messages through Paging Control Channel (PCH) from Base Station (BS) at the same time, resulting in significant power consumption.

Therefore, in this paper, we propose an efficient power-saving mechanism for integration of WLAN and cellular networks, where if certain time (defined later as $\epsilon$) is expired just after the WLAN interface enters the idle state, the interface is turned off without any periodic wake-up for beacons in order to save power consumption. In addition, the existing paging of cellular network is utilized on behalf of the beacons of WLAN in case of need to turn on the WLAN interface due to incoming data from long-lived multimedia data. Accordingly, our aim will be to allow for WLAN interface with higher-power consumption during idle period than cellular network interface, to remain off for a longer period of time. Therefore, we propose using relatively lower-power PCH to wake up the WLAN interface. For the proposed scheme, the mean power consumption is investigated via both numerical and simulation results.

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TABLE I
DETAILED PROCEDURE OF THE PROPOSED POWER SAVING MECHANISM FOR DOWNLINK TRAFFIC

| |
|---|
| **(1)** When MN's WLAN interface is in inactive state, data traffic comes into a per-user-buffer at the RNC. **(2)** Once the number of packets in the buffer reaches a threshold $N$, the BS notifies the MN about the existence of downlink data by using its existing periodic paging. **(3)** On receiving the notification, WLAN interface is turned on (i.e. goes to active state) and an available AP is found. If no APs are found, the data transmission is performed through the cellular network. **(4)** A WLAN_IF_READY message is sent to the corresponding 802.11 gateway while receiving the incoming data through the cellular network. **(5)** Upon receiving the WLAN_IF_READY message, the 802.11 gateway sends a VERTICAL_HANDOFF_COMPLETE message including the SSID and MAC address of the AP selected for the MN. **(6)** Once the SGSN receives the VERTICAL_HANDOFF_COMPLETE message, it starts to forward the remaining data to the 802.11 gateway instead of to the BS. **(6)** The 802.11 gateway transmits the remaining data received from the SGSN to the MN. |

## II. EFFICIENT POWER-SAVING MECHANISM

In our system, turning off the WLAN interface removes the power-consuming process of detecting WLAN's signal strength. On the other hand, in the idle state, the cellular network interface is assumed to listen continuously to the PCH to detect messages directed to APs in its cell in addition to the messages addressed to it. This assumption is valid since the cellular network interface has to support the operation of relatively more frequent traffic (e.g. Multimedia Messaging Service) compared with data traffic in WLAN.

In this study, we focus on downlink traffic because it is envisioned that 4G wireless system's traffic pattern will be highly asymmetrical more favoring the downlink. Basing our power-saving mechanism on 3GPP system, for downlink transmission, BS notifies MN when the number of packets in a per-user-buffer at Radio Network Controller (RNC) [3] reaches a certain threshold $N$ (usually, less than the buffer size) so that the MN should not consume its power due to frequent turn-on and off actions which might occur if MN should be awakened upon receiving a packet from cellular network.

We adopt a tightly-coupled approach [2] that makes WLAN appear to the 3G core network as another 3G access network so that the paging of a cellular network can be utilized to provide information about all APs in its current cell. We assume that the Serving GPRS Support Node (SGSN) has an acquisition of the IP addresses and Service Set Identifiers (SSIDs) of all APs in its coverage, wherein the 802.11 gateways serving the APs have a direct link to the SGSN either when the BSs are initialized or when additional APs are installed in the SGSN coverage area.

Table I and Fig. 1 show the detailed procedure of the vertical handoff and the interface selection for downlink traffic under the proposed power-saving mechanism for which more detailed structure of the proposed signaling and the analysis of RNC buffer with threshold $N$ are presented in [4]. In

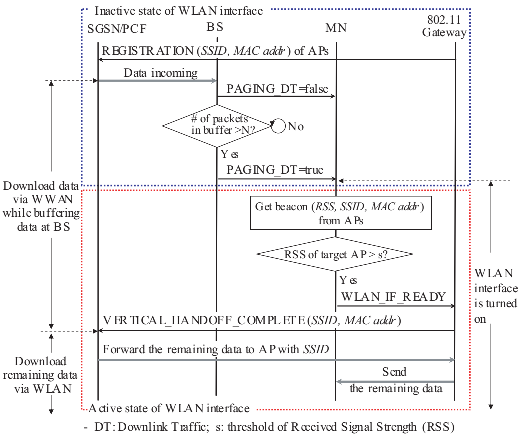


Fig. 1. Signaling procedure when WLAN interface goes from inactive state to active state to receive downlink traffic.

our power-saving mechanism, WLAN interface is prevented from being turned on for transient traffic. In step (2) of Table I, especially for long-lived multimedia internet traffic, the content of buffer reaches $N$ so quickly. Accordingly, the RNC keeps forwarding the data while the WLAN interface is being turned on.

## III. An Analytical Model of WLAN Interface

When cellular network paging is used for WLAN, before WLAN interface is manually turned off, the possible WLAN interface states are

- *Communication state*: A WLAN interface sends or/and receives data in this state that is left for *Idle* state when the data session completes.
- *Idle state*: Once the WLAN interface transits from *Communication* state to this state, an *Idle* timer is set and starts to decide whether to turn off the WLAN interface or not. When the timer expires ($T_{23}$), the threshold of which is $\epsilon$, the WLAN interface enters *Inactive* state. Before the timer expiration, if a data session arrives to the WLAN interface ($t_{21}$), the WLAN interface goes back to the *Communication* state.
- *Inactive state*: The WLAN interface is completely turned off expecting that the user would not be using the Internet any longer on his/her mobile device.

We assume that the traffic session arrivals to a WLAN interface form a Poisson process with arrival rate $\lambda_d$ and $\lambda_u$ for downlink and uplink, respectively. Let the session holding time be exponentially distributed with mean $1/\mu$.

Fig. 2 shows the state transition diagram of WLAN interface using cellular network paging, where the behavior of a WLAN interface can be described as a semi-Markov process. Let $\pi_i$ and $p_{ij}$ be the stationary probability of state $i$ and the state transition probability from state $i$ to $j$. Then, we have the stationary state probabilities of an embedded Markov chain by solving

$$\bar{\pi} = \bar{\pi}\mathbf{P}, \qquad \sum_{i=1}^{3} \pi_i = 1 \tag{1}$$

where $\bar{\pi}$ denotes the probability vector as $[\pi_1, \pi_2, \pi_3]$ and $\mathbf{P}$ is the transition probability matrix as consisting of elements $p_{ij}$.

Here, it is obvious that $p_{12} = 1$ and $p_{31} = 1$ because exit from the *Communication* and *Inactive* states is caused by only

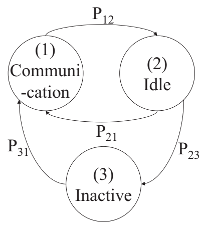


Fig. 2. State transition diagram of WLAN interface for WLAN using cellular network paging.

one event of turning on the interface and session completion, respectively. Thus, solving Eq. 1 yields

$$\begin{aligned} \pi_1 = \pi_2 &= \frac{1}{2 + p_{23}} \\ \pi_3 &= \frac{p_{23}}{2 + p_{23}}. \end{aligned} \tag{2}$$

Under the assumption that the traffic session arrivals follow a Poisson process, $t_{21}$ can be regarded as an exponential random variable with mean $\frac{1}{\lambda_d + \lambda_u}$. Then, we have

$$\begin{aligned} p_{23} &= \int_0^{\infty} f_{T_{23}}(t) Pr[t_{21} > t] dt \\ &= \int_0^{\infty} \delta(t - \epsilon) e^{-(\lambda_u + \lambda_d)t} dt \\ &= e^{-(\lambda_u + \lambda_d)\epsilon}. \end{aligned} \tag{3}$$

The mean sojourn times of an MN in state $i$, $\bar{t}_i$ are given by

$$\begin{aligned} \bar{t}_1 &= \frac{1}{\mu} \\ \bar{t}_2 &= E[\min(t_{21}, T_{23})] \\ &= \int_0^{\epsilon} t(\lambda_d + \lambda_u) e^{-(\lambda_d + \lambda_u)t} dt \\ &\qquad + \int_0^{\infty} t f_{T_{23}}(t) Pr[t_{21} > t] dt \\ &= \int_0^{\epsilon} t(\lambda_d + \lambda_u) e^{-(\lambda_d + \lambda_u)t} dt + \epsilon e^{-(\lambda_d + \lambda_u)\epsilon} \\ &= \frac{1 - e^{-(\lambda_d + \lambda_u)\epsilon}}{\lambda_d + \lambda_u} \\ \bar{t}_3 &= \frac{1}{\lambda_d + \lambda_u}. \end{aligned} \tag{4}$$

The steady state probabilities of a semi-Markov process for WLAN interface can be obtained by solving

$$P_i = \frac{\pi_i \bar{t}_i}{\sum_{j=1}^{3} \pi_j \bar{t}_j}, \quad i\text{=1,2,3}. \tag{5}$$

Therefore, substituting Eqs. 2, 3 and 4 into Eq. 5 results in $P_1 = \frac{\lambda_d + \lambda_u}{\lambda_d + \lambda_u + \mu}$, $P_2 = \frac{(1 - e^{-(\lambda_d + \lambda_u)\epsilon})\mu}{\lambda_d + \lambda_u + \mu}$, and $P_3 = \frac{e^{-(\lambda_d + \lambda_u)\epsilon}\mu}{\lambda_d + \lambda_u + \mu}$.

Let $c_{ic}$ and $c_{iac}$ denote the power consumed to wake up MN from *Idle* and *Inactive* states, respectively, to go to *Communication* state. Given the power-consumption per unit time $t$ during *Communication* and *Idle* states denoted by $c_c$ and $c_i$, respectively, finally, we can compute the power consumed during time period $t$ as followings:

$$Pw = t(c_c P_1 + c_i P_2 + c_{iac} P_3 p_{31} + c_{ic} P_2 p_{21}) \tag{6}$$

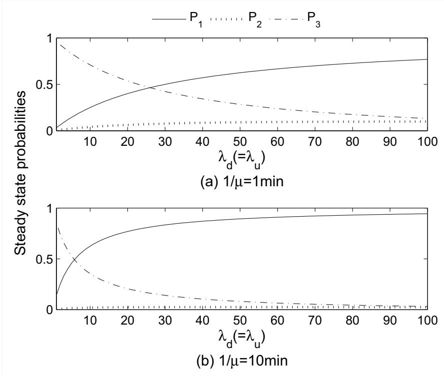


Fig. 3. Steady state probabilities versus session arrival rate.

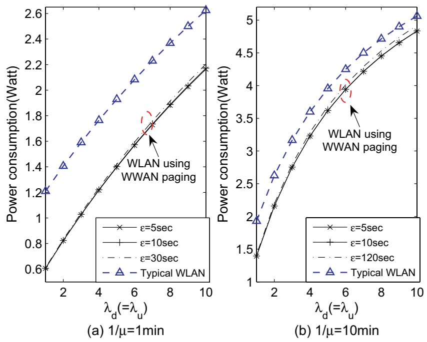


Fig. 4. Power consumption for WLAN using cellular network paging and typical WLAN.

where the power consumption in *Inactive* state becomes zero because the interface is completely turned off. From Eq. 3 and the above mentioned fact that $p_{31} = 1$, Eq. 6 is restated as

$$Pw = t(c_c P_1 + (c_i + c_{ic}(1 - e^{-(\lambda_u + \lambda_d)\epsilon}))P_2 + c_{iac} P_3). \quad (7)$$

The behavior of a typical WLAN interface is investigated as a simpler form of Fig. 2, excluding the *Inactive* state. We can easily know the state probabilities, $\pi_i$ $(i = 1, 2)$ and the mean sojourn times, $t_i$ $(i = 1, 2)$ as $\pi_1 = \pi_2 = \frac{1}{2}$ and $\bar{t}_1 = \frac{1}{\mu}$ and $\bar{t}_2 = \frac{1}{\lambda_d + \lambda_u}$. Thus, the state probabilities of a semi-Markov process for a typical WLAN interface are given by $P_1 = \frac{\lambda_d + \lambda_u}{\lambda_d + \lambda_u + \mu}$ and $P_2 = \frac{\mu}{\lambda_d + \lambda_u + \mu}$. Then, for typical WLAN, the power consumption during time period $t$ is

$$Pw = t(c_c P_1 + (c_i + c_{ic})P_2). \quad (8)$$

## IV. Performance Evaluation

We will now present several numerical and simulation results to demonstrate the power saved by our proposed mechanism. Fig. 3 shows the effect of traffic session arrival rate on steady state probabilities for $1/\mu$ =1 and 10$m$ when $\epsilon$=10$s$. We set $c_c$, $c_i$, $c_{ic}$, and $c_{iac}$ to 7.5, 0.75, 0.17 and 0.37, respectively. If the session arrival rate is high, it is more likely that MN goes directly to *Communication* state from *Idle* state without passing by *Inactive* state. Thus, the probability, $P_1$ increases while $P_3$ decreases as $\lambda_d$ and $\lambda_u$ increase. The probability, $P_2$ is almost constant under varying $\lambda_d$ and $\lambda_u$. Accordingly, our proposed mechanism saves more power before the crossing point of $P_1$ and $P_3$ curves than after the point, so that for traffic session arrival rate ranging from 1 to 10 (per hour) within the interval from 1 up to the cross point in Fig. 3, we present numerical results of the power consumption (Watt) in Fig. 4 for different values of $\epsilon$. We compare here between the proposed mechanism and typical WLAN. For the proposed mechanism, the result in Fig. 4 is based on Eq. 7 while the power consumption for typical WLAN is calculated by Eq. 8 when unit time $t$=1$s$. We observe that the proposed mechanism shows a considerable reduction in power consumption compared to typical WLAN. The *Idle* timer value $\epsilon$ is assumed to be much shorter compared to the session duration, the maximum of which is 30 and 120 $s$ for $1/\mu$=1 and 10 $m$, respectively. Thus, the power consumption very slightly increases with the increase of $\epsilon$. The improvement of the proposed mechanism over typical WLAN decreases as $1/\mu$ is increased (See Fig. 4(b)) due to the increase of communication (i.e. session) duration.

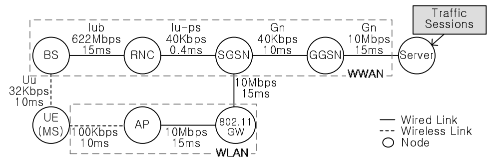


Fig. 5. Simulation network topology.

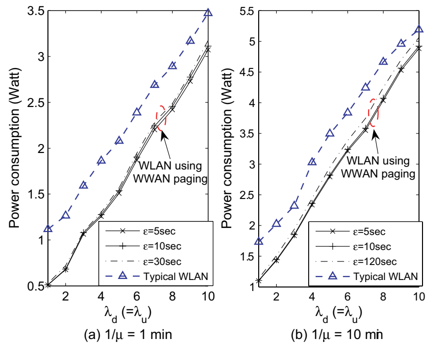


Fig. 6. Simulated power consumption for WLAN using cellular network paging and typical WLAN.

To demonstrate the analytical model, we performed simulation tests over a sample network topology as shown in Fig. 5 by using ns2 [5]. For each simulation, traffic sessions arrived according to a Poisson process. We see that the simulated power consumption in Fig. 6 is consistent with the analytical results in Fig. 4.

## V. Conclusion

In this letter, we proposed an efficient power-saving mechanism using paging of cellular network for WLAN in heterogeneous wireless networks and an analytical model was also provided to evaluate the power consumption for the proposed mechanism and typical WLAN. We have demonstrated by simulation and analytical results that the proposed method reduces more power consumption compared to typical WLAN.

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